Overall Objective:

- Determine the influence of impact damage on fatigue life of γ - Ti-24Al-2Nb-2Cr simulated low pressure turbine blades.

Microstructural DOE Objectives:

- Determine the effect of energy, specimen thickness, hardness of projectile, and impact temperature on degree of cracking in γ - TiAl.

- Down select a few impact conditions for follow-on fatigue study.

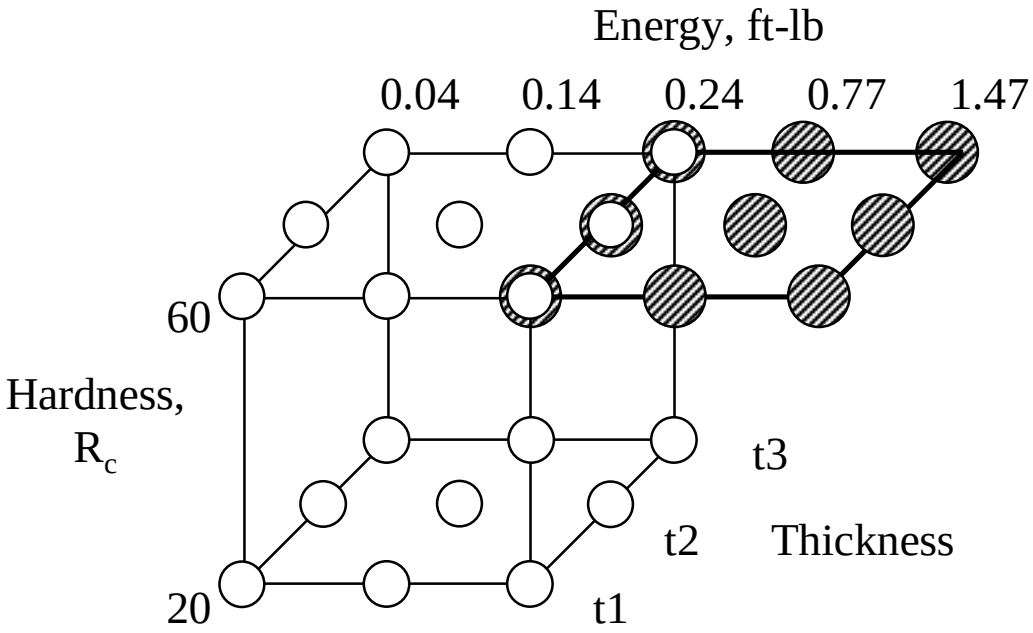
Fig. 1

Microstructural Analysis DOE's

Phase

II — 1.6 mm BB's (1/16")

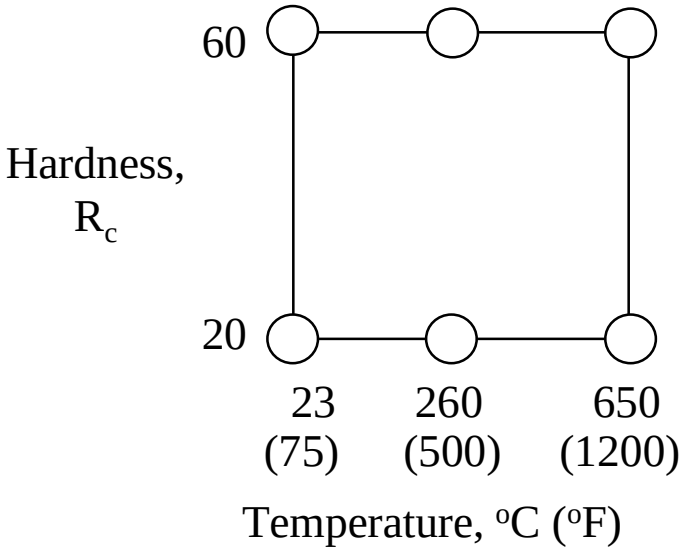
I — 3.2 mm BB's (1/8")



- 260 °C (500 °F)
- Energy = 0.05 — 2 J (0.04-1.47 ft-lb)

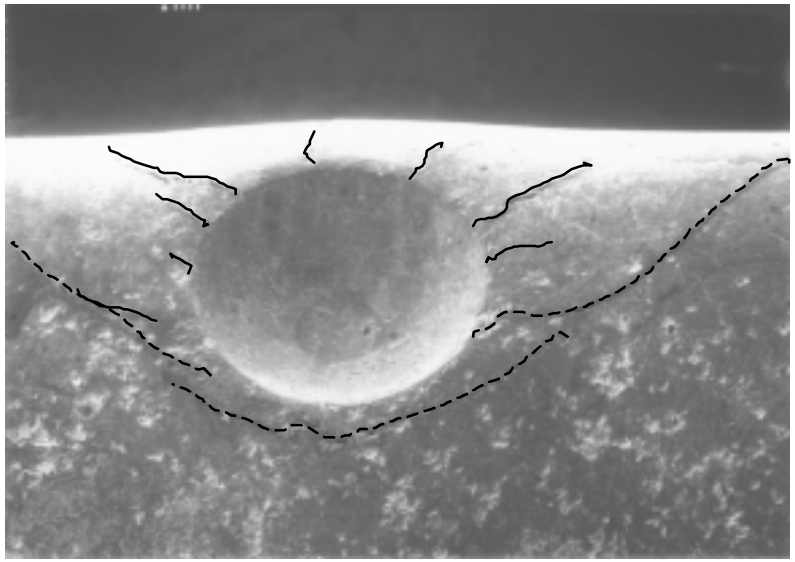
Side Experiment

— 1.6 mm BB's (1/16")



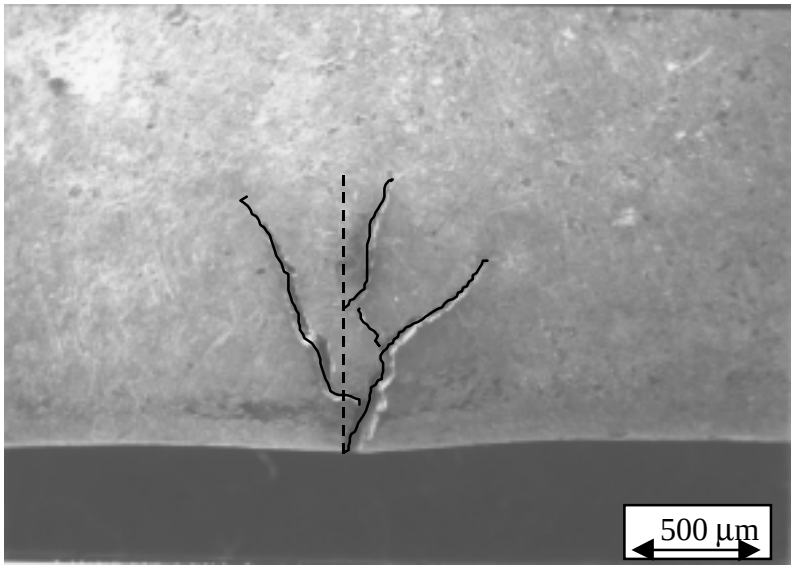
- Thick Specimens
- Energy = 0.19 J (0.14 ft-lb)

Crack Length Measurements



Frontside Major

Frontside Total



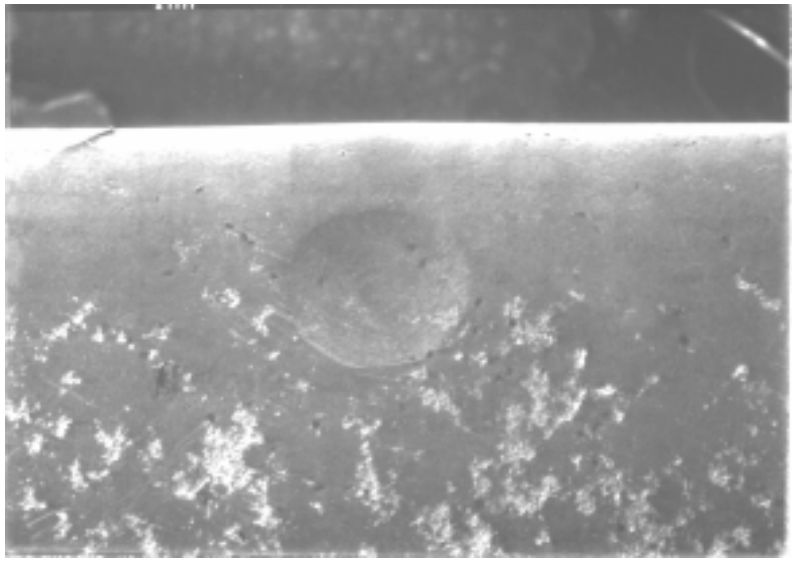
Backside Straight

Backside Total

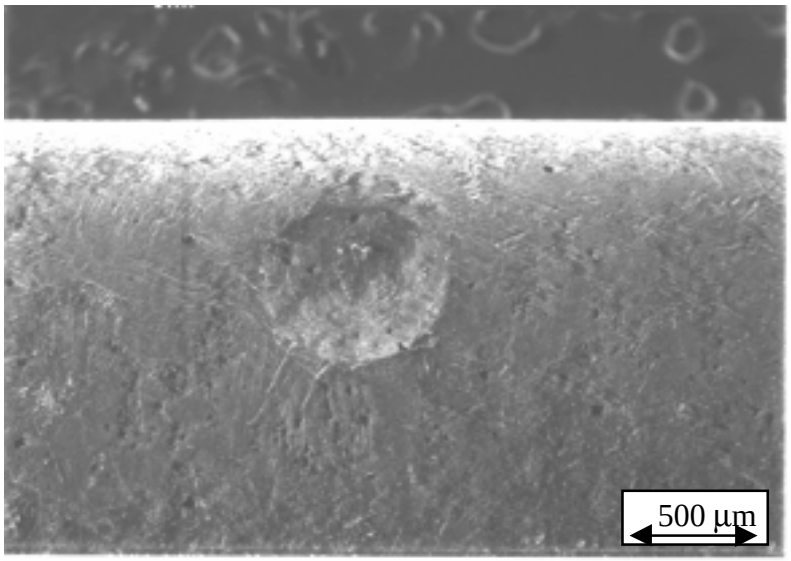
Fig. 4

Front Side Damage

Low Energy Impacts, E= 0.05 J (0.04 ft-lb)
1.6 mm (1/16”) Projectiles



Thin Specimen

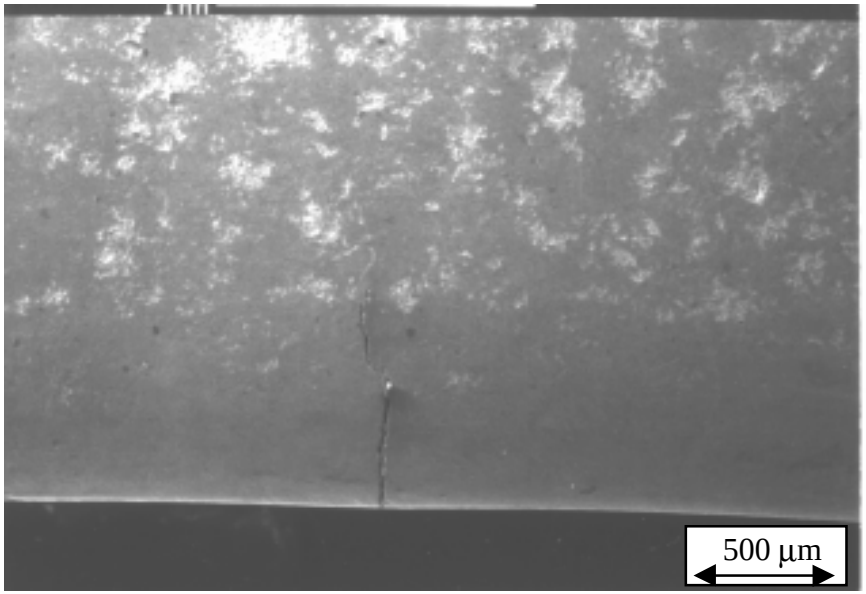


Thick Specimen

Fig. 5

Back Side Damage

Low Energy Impacts, E = 0.05 J (0.04 ft-lb)
1.6 mm (1/16”) Projectiles



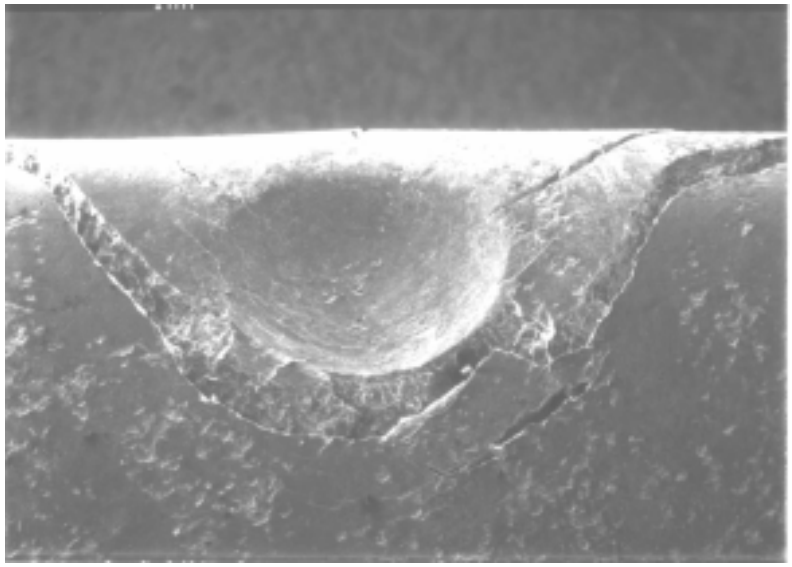
Thin Specimen

*No back side cracks were detected on the surface of the thick specimens.

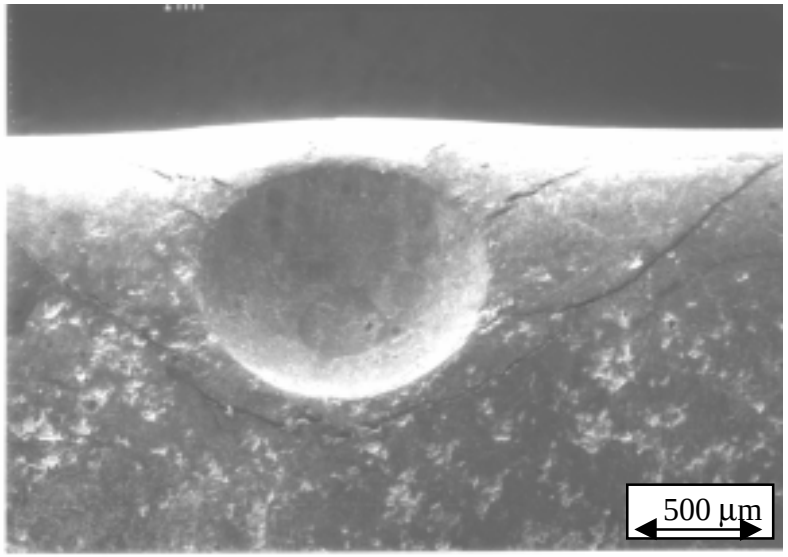
Fig. 6

Front Side Damage

High Energy Impacts, E = 0.33 J (0.24 ft-lb)
1.6 mm (1/16”) Projectiles



Thin Specimen

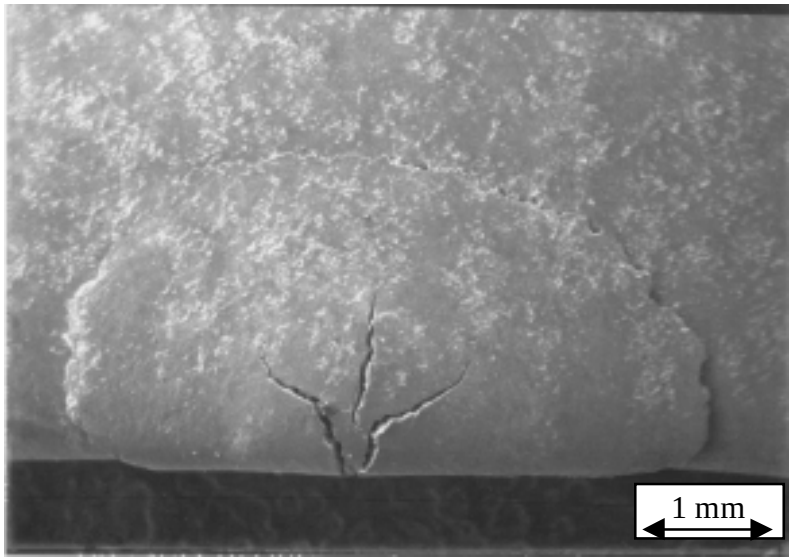


Thick Specimen

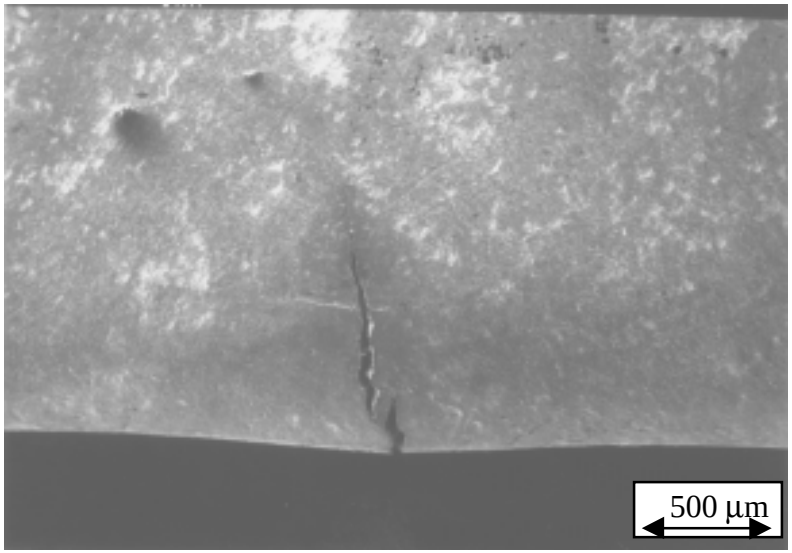
Fig. 7

Backside Damage

High Energy Impacts, E = 0.33 J (0.24 ft-lb)
1.6 mm (1/16”) Projectiles



Thin Specimen



Thick Specimen

Fig. 8

Projectile Hardness Had No Effect on Backside Straight Crack Length

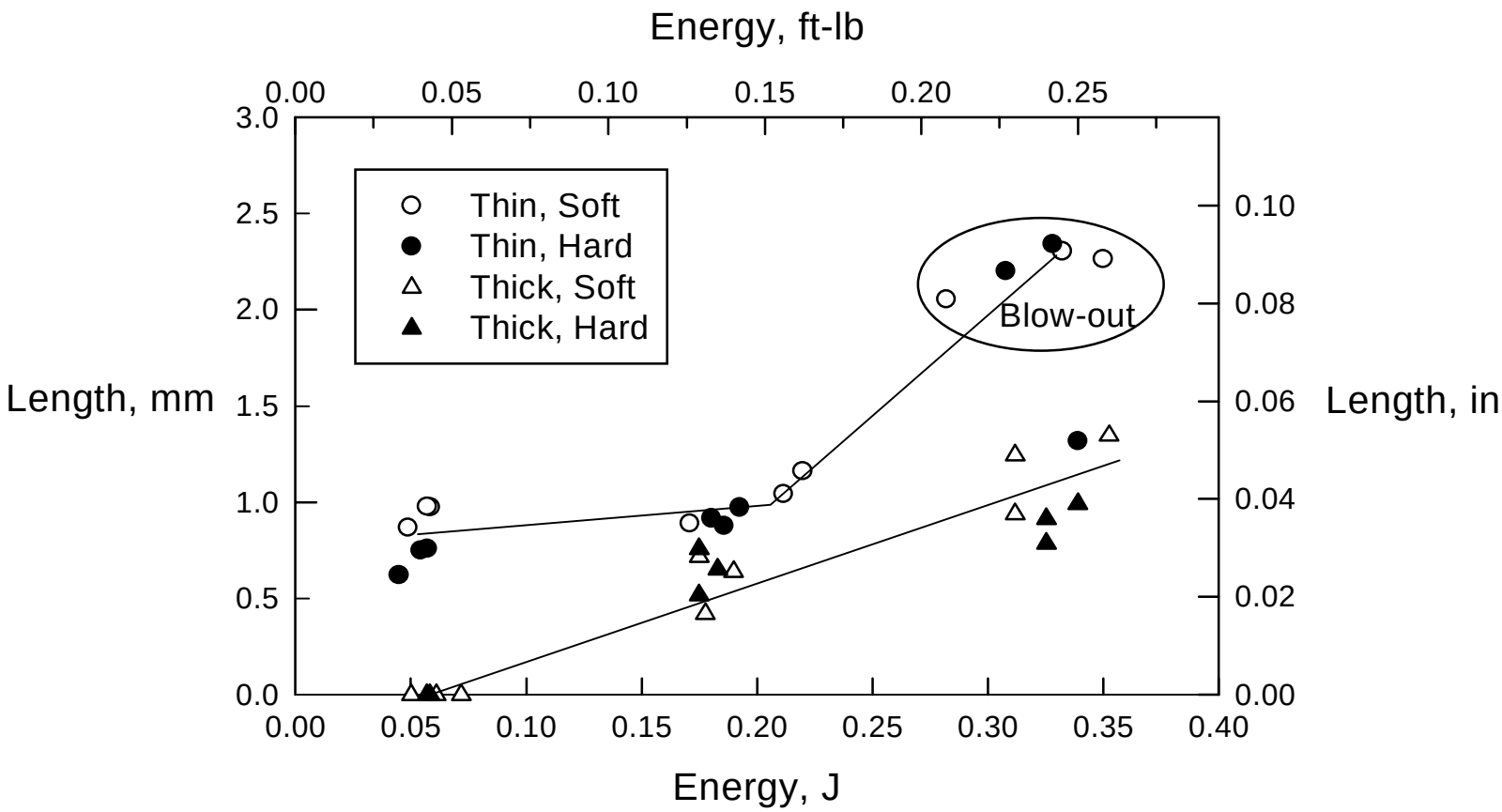
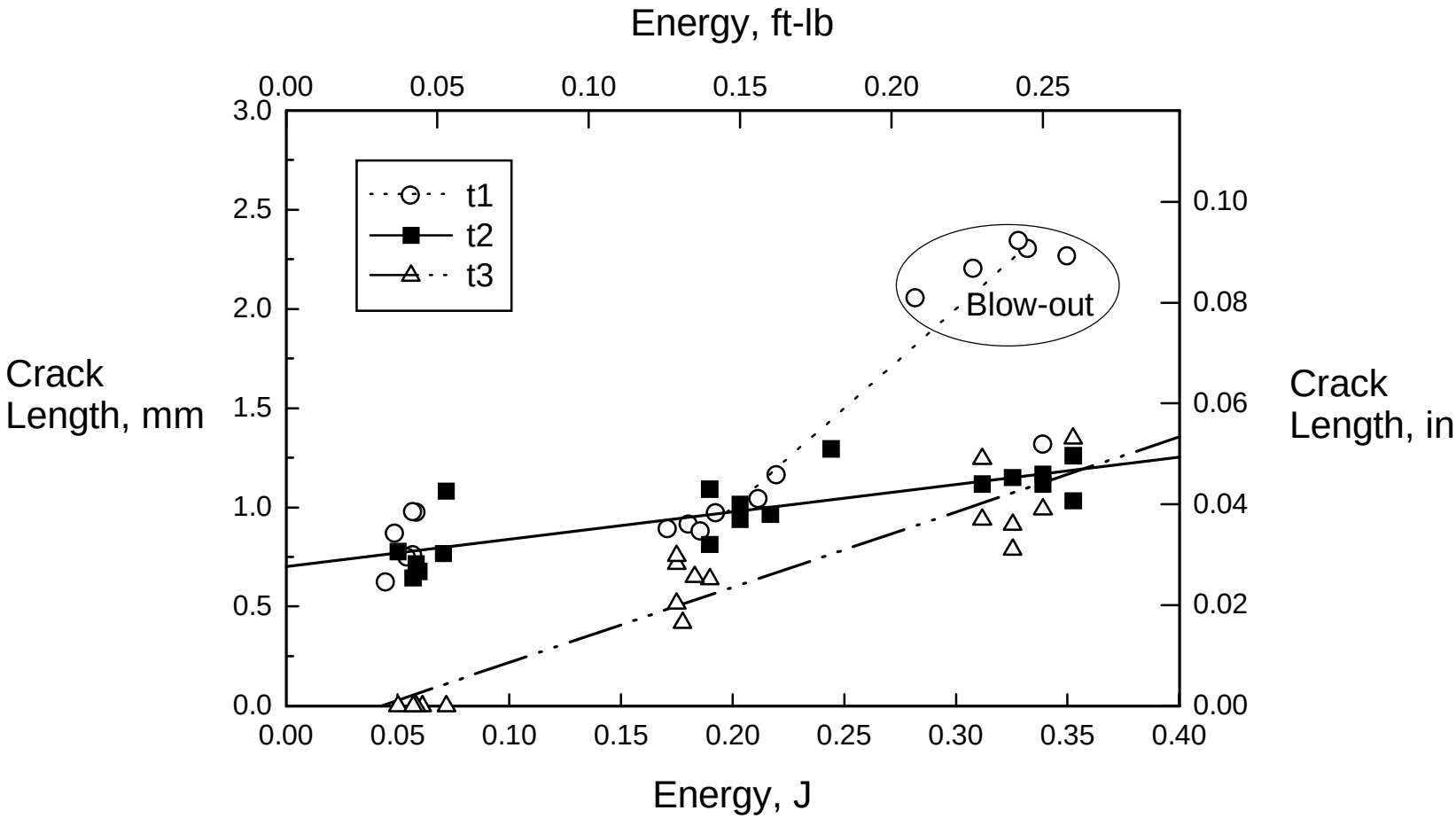


Fig. 9

Thick Specimens Exhibited Improved Impact Resistance

Criterion: Backside Straight Crack Length



Large and Small Projectiles Resulted In Similar Damage at Equivalent Energies

- Hard and Soft Projectiles

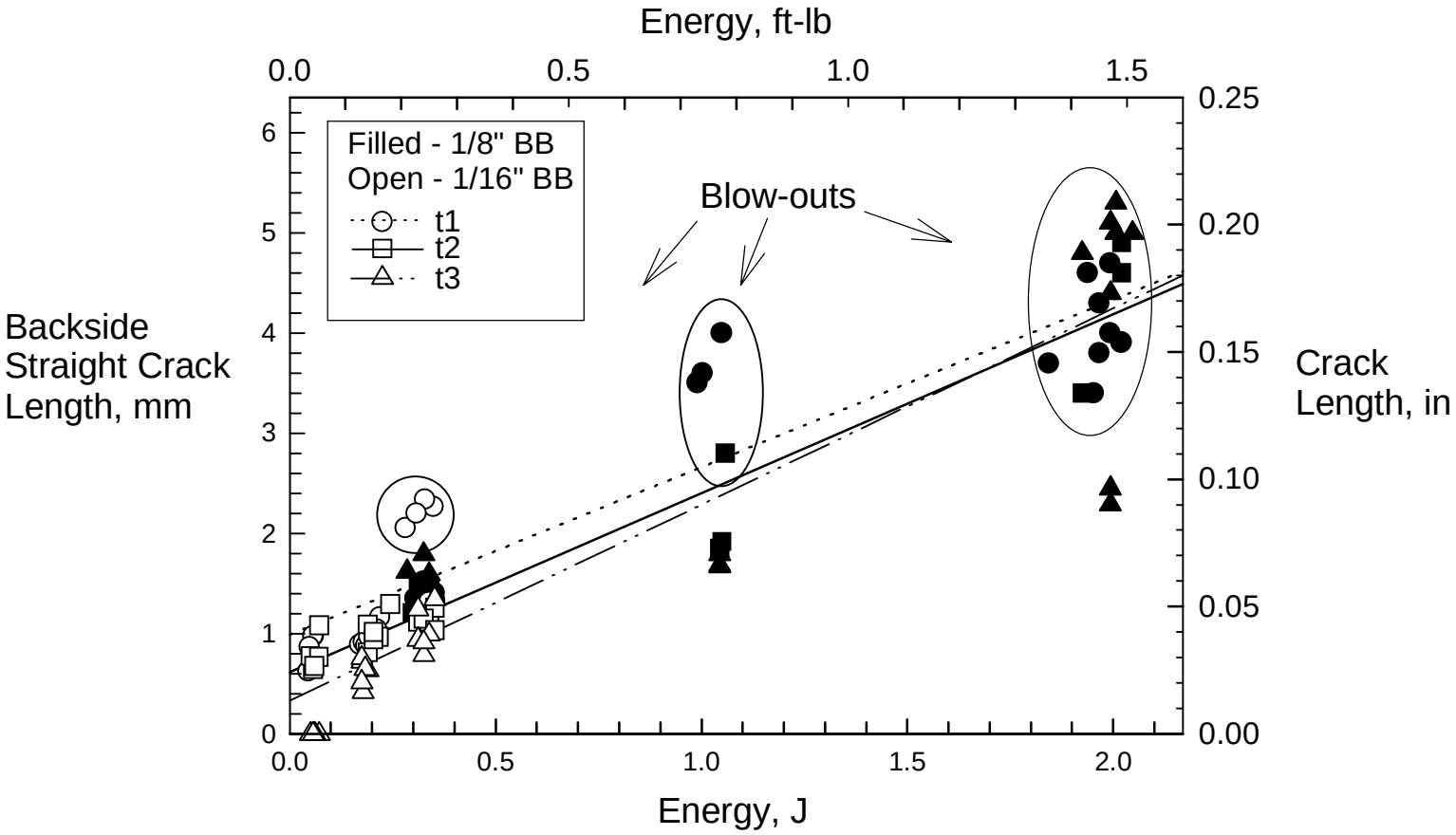
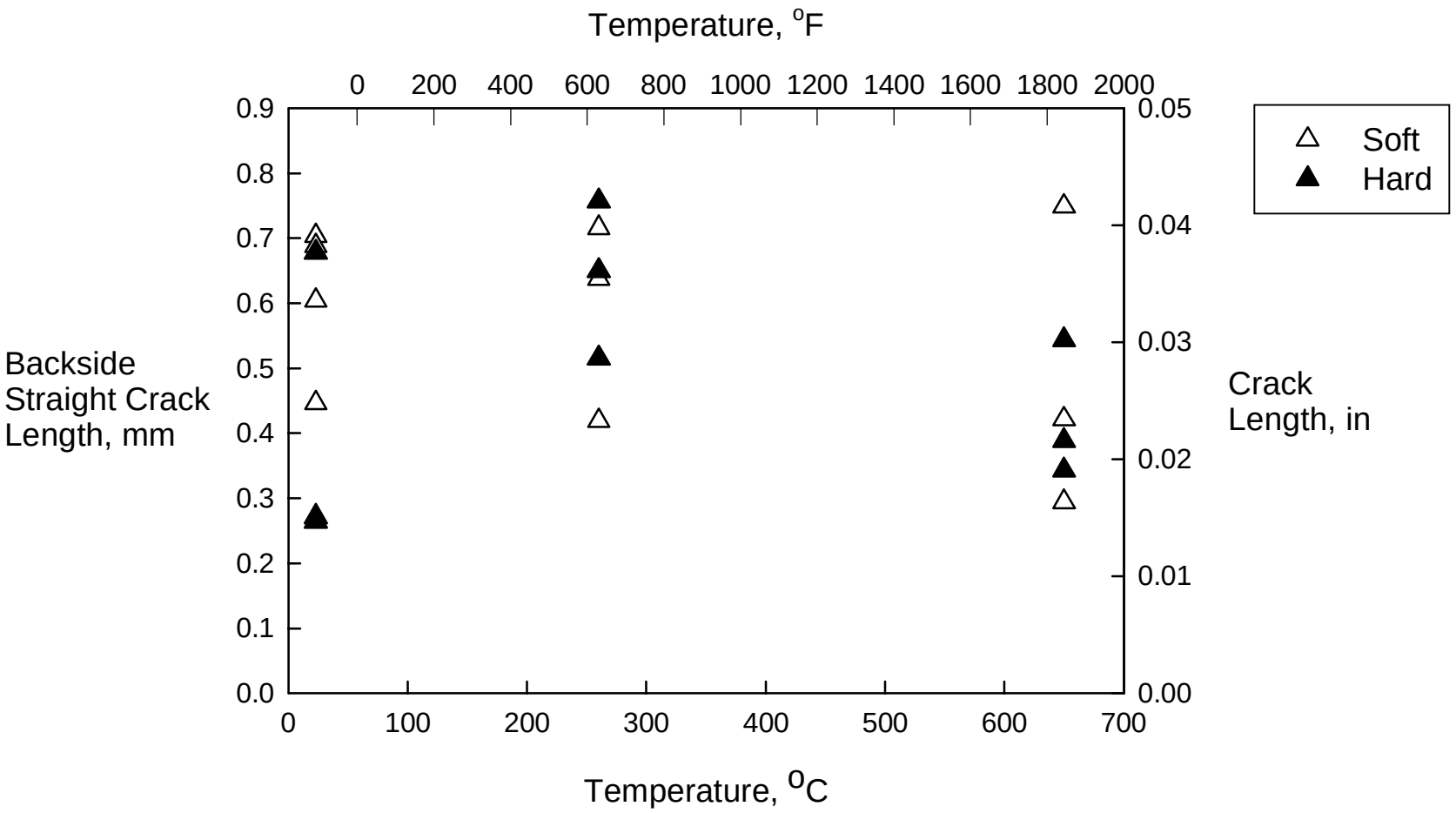


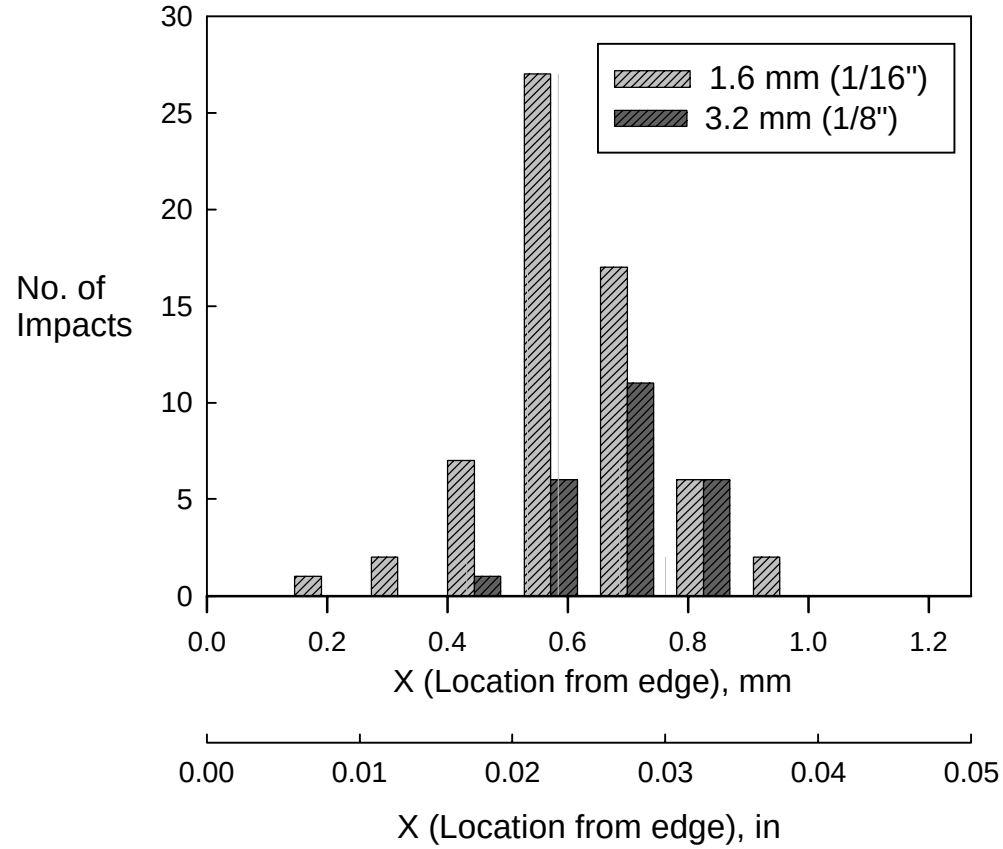
Fig. 11

Temperature Had No Effect on Backside Crack Length

Thick Specimens Impacted at Medium Energy



Aim Accuracy Was Better for Large Projectiles



1.6 mm (1/16 ") Projectiles

$\overline{X}$ = 0.61 mm (0.024")
C.I. = 0.28 mm (0.011")
Aim = 0.51 mm (0.020")

3.2 mm (1/8") Projectiles

$\overline{X}$ = 0.69 mm (0.027")
C.I. = 0.19 mm (0.008")
Aim = 0.64 mm (0.025")

Fig. 13

Effect of X Position on Front Total Crack Length

- Thick Specimens Impacted at Medium Energy
- Hard and Soft BB's

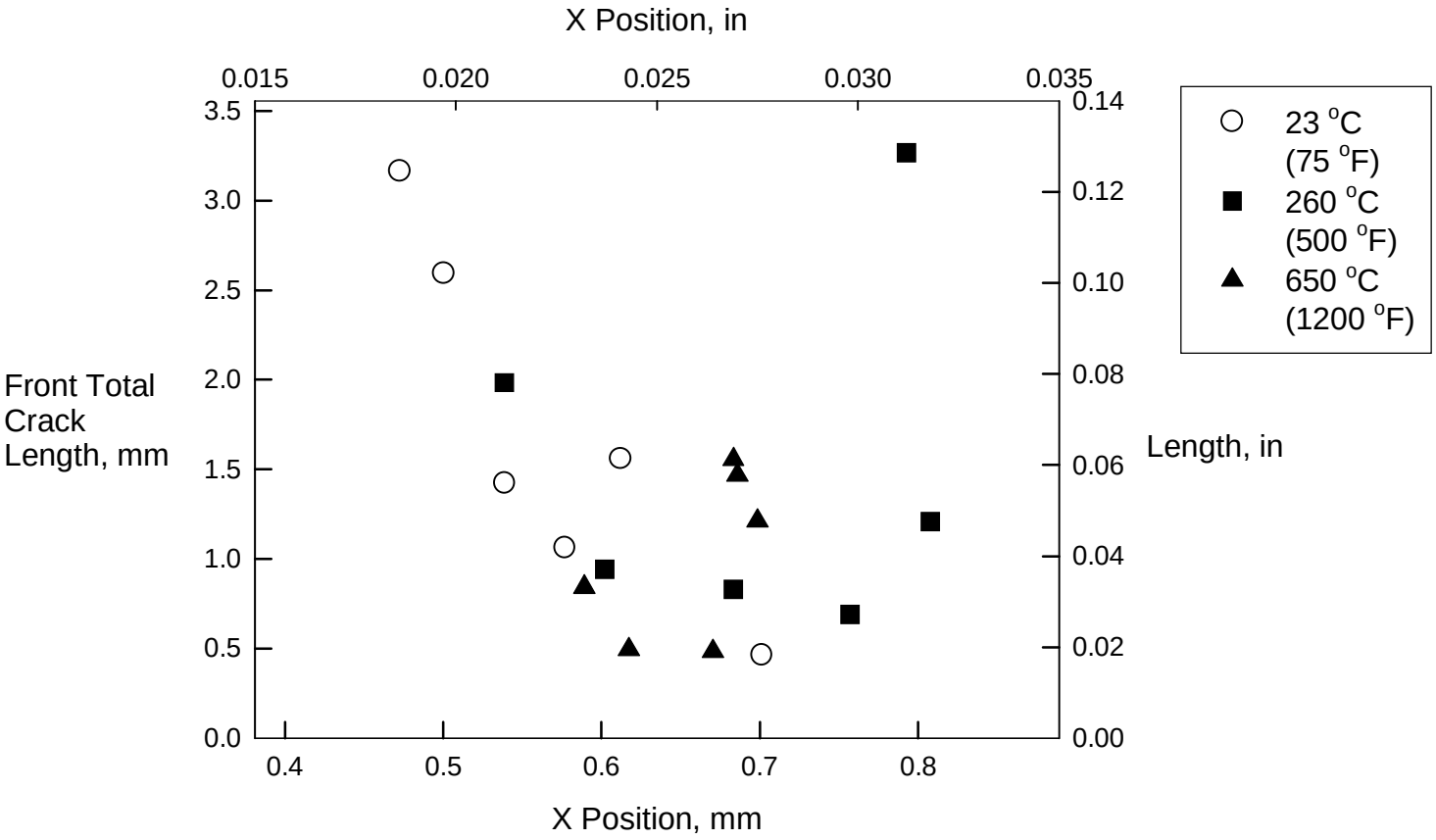


Fig. 14

X Position Was Not Correlated to Backside Straight Crack

- Thick Specimens Impacted at Medium Energy
- Hard and Soft BB's at 75, 500, and 1200 ^{o}F

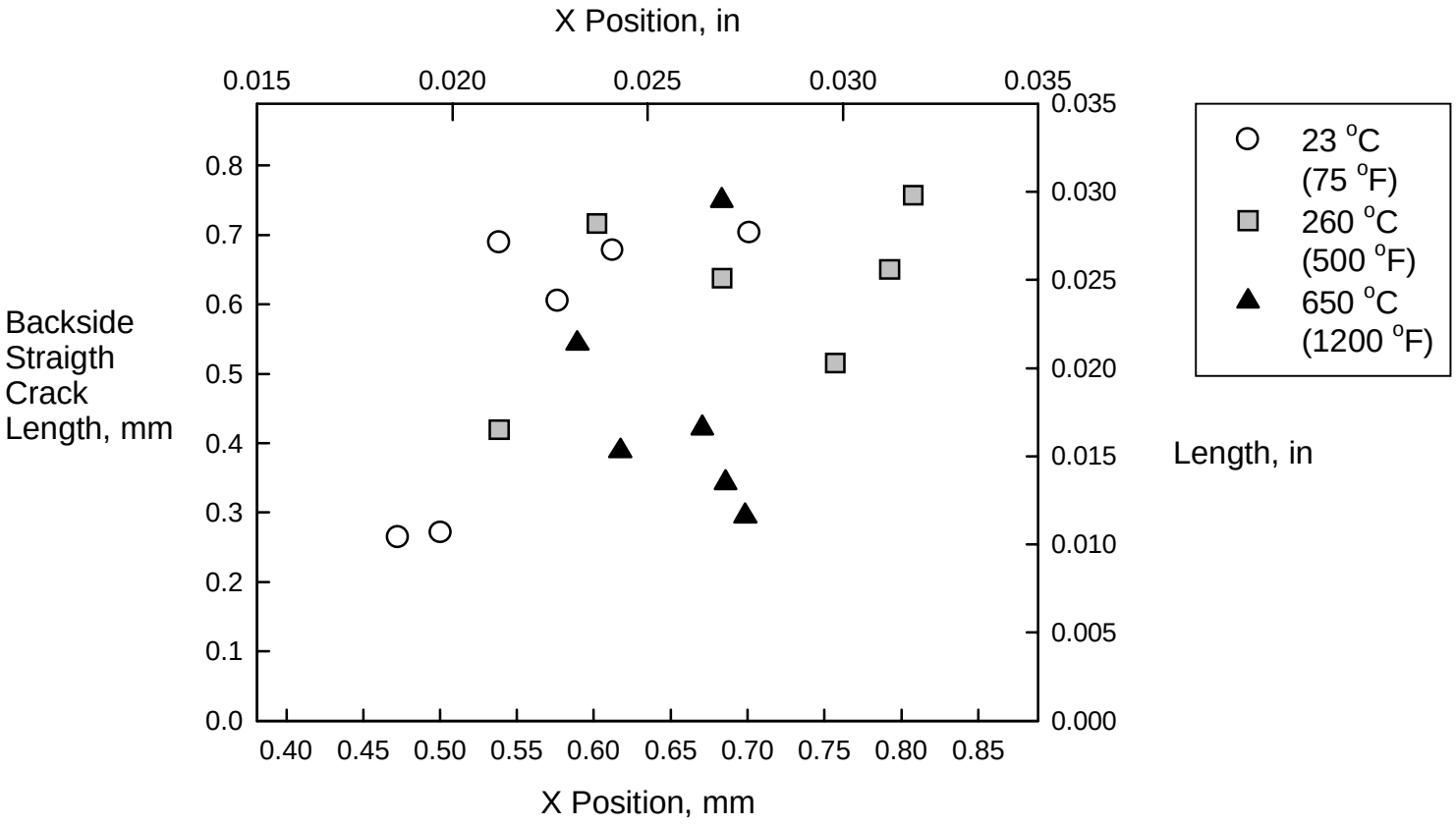


Fig. 15

Preliminary Summary of Effects from DOE Models

Crack Type	Main Effects				Interactive Effects						Quadratic Effects			R^2
	E	t	H	x	E*t	E*H	E*x	t*H	t*x	H*x	E^2	t^2	x^2	
Front Major	✓	✓		✓							✓	✓		86
Front Total	✓	✓	✓			✓								87
Back Straight	✓	✓	✓ [b]				✓	✓	✓				✓	89
Back Total[a]	✓	✓	✓ [b]		✓				✓	✓	✓	✓		88

[a] Statistician recommended square root transforms of data to achieve R^2 of 93% for Back Total Crack Length.

[b] Trend of effect opposite than expected.

Summary

1. Energy had the largest effect on crack length.

2. Projectile hardness had little effect on impact damage.

3. The thin and medium thickness specimens exhibited similar impact resistance while the thick specimens had improved impact resistance.

4. Large and small projectiles resulted in similar damage at equivalent energies.

5. Front and backside crack lengths were not well correlated. It is unknown, at this time, which crack type will best correlate to fatigue strength.

6. Temperature had little effect on crack lengths.

7. Aim was more accurate for the large projectiles.

8. X position was generally modeled only as an interactive effect.

Conclusions

- The experimental impact conditions chosen produced a spectrum of damage from minor denting to major cracking.
- The actual damage tolerable for LPT blade application will be determined by a combination of fatigue testing and consideration of actual engine conditions.
- Low pressure turbine blades should be as thick as possible for improved impact resistance.
- With thickness held constant, the initial selection of impact variables can be down selected to energy for the follow-on fatigue study.
- Some variation in impact location can be tolerated, especially with the thick specimens.